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Integration of academic advising into a first-year engineering design course and its impact on psychological constructs

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Introduction and Summary

Engineering educators often look to imbue students with behaviors or traits beyond the retention and recall of facts, or the understanding of concepts taught in class. Many of these traits are not cognitive, but rather psychological in nature, such as *self-efficacy*, *curiosity*, perseverance (*grit*), and *creativity*. These and other psychological constructs are often measured and correlated to traditional aspects of student performance[1]. In contrast, they are seldom measured to determine whether they are influenced by specific academic interventions. For example, the literature on active learning, problem-based learning, and peer learning are rife with claims that they either cultivate or depend upon curiosity and creativity, yet we are unaware of any direct assessments that demonstrate that this is so. In engineering education, pre-post quantitative comparisons of these psychological constructs in response to instructional interventions appear to be wholly lacking.

We thus sought to answer two questions: (a) similar to knowledge and comprehension, are *grit, curiosity, creativity*, and *self-efficacy* mutable by an active educational environment, and (b) does a learning environment that incorporates academic advising offer additional benefit in bolstering these traits? So-called "intrusive advising" is believed to increase academic performance and persistence in majors (reviewed in Banta *et al.* [2]). We hypothesized that the effects of intrusive advising would reach beyond these usual academic indicators to influence the above-named psychological constructs as well.

Two sections of an introductory engineering design course were assessed, each with the same instructor, to determine if learning environment affects the above four traits over the course of a single semester. One section emphasized in-class advising, with the instructor serving as the academic advisor to each student in the class. The other section, which served as the control group, spent equivalent time in group project meetings. Both sections of the course engaged in intensive design-build activities for the duration of the semester. Psychometric assessments of the constructs were delivered twice – once at the beginning and once at the end of the semester.

We found that the learning environment with integrated advising yielded lesser improvements than the control environment that placed greater emphasis on team meetings. This effect extended to aspects of all four of the psychological constructs measured here – but was statistically significant for *engineering design self-efficacy*, and *creativity*. We believe that this surprising result may be due to the inadvertent forcing of repetitive brainstorming in the control group during their weekly meetings. This repetitive brainstorming has been shown previously to increase *self-efficacy* and *curiosity*[3].

Our data suggest that an expanded suite of educational assessments that includes psychometrics may help improve engineering education by revealing changes beyond those measured for summative grading. Further, our data show that brainstorming throughout a semester might improve non-cognitive qualities that are held in high regard in engineering. In contrast, while unusually intensive academic advising may benefit students in other ways, it does not directly improve these same qualities.

Course Design and Interventions

Our interventions and assessments were introduced to two sections of the course "Introduction to Engineering." The same instructor taught both sections; thus any differences we observed would more probably be due to the intervention. Additionally, a graduate teaching assistant (GTA) facilitated each class.

Each section was centered on an intensive design-build project. Students were challenged to come up with products to solve an "annoying" everyday problem. They subsequently engaged in two rounds of design, prototyping, and testing to ensure that they experienced iteration in the design process. Products ranged from improved bicycle locks to a product for detecting when a patient leaves their bed in a clinical care setting. At each stage of design – from conceptualization, to the initial and final prototypes – students maintained electronic lab books and made presentations. Along the way the students were taught CAD, were introduced to shop safety, and were required to use a variety of tools including:

- Table saws
- Wood and metal band saws
- Drill presses
- Grinders and sanders
- Sewing machines
- Microcontrollers (Arduino)
- Laser cutters
- 3D printers

The design-build activities constituted 9 of the ~14 weeks of instruction. Thus the hands-on emphasis was unusually high.

At the end of the course, each team generated an invention disclosure report in the format for submission to the University's office governing intellectual property (U.Va. Licensing and Ventures Group). The report also needed to include comprehensive CAD drawings of their product along with test results on their prototype.

Intervention: The instructor served as the academic advisor for each of the students in the advising-intensive section. He met with them individually, required that they each attend five events to expand their utilization of campus resources, and incorporated several in-class discussions on topics including:

- pedagogy
- choosing an engineering major
- first year academic advising
- preparing for a career
- stress management and support resources

This combination of advising with instruction was envisioned by Dr. Edward J. Berger and Dr. Archie L. Holmes, and supported by the Office of the Provost.

Control: In the non-advising section (control), we spent an equivalent amount of time instead in weekly team progress meetings. The instructor and the GTA spoke with each group independently for about 8 minutes to see how their team was functioning, what progress they had made, what materials they might need, and to give advice on their design. The control section of the course was taught in the hour immediately before the advising section.

Study Design

Our study was reviewed and found exempt by our Social and Behavioral Sciences Institutional Review Board (project # 2014-0302-00). Psychometric assessments were delivered twice – once during the first week of classes and again during the final exam week.

Curiosity: Many studies of curiosity as a psychological construct have been subject to the vagaries of language surrounding the term. However, one well-validated approach divides curiosity into two dimensions:

1. *Exploration* (alternatively "stretching") refers to appetitive seeking out of novel and challenging information or experiences; and
2. *Absorption* (alternatively "embracing") refers to the propensity to be fully engaged in activities [4].

We measured both using the "Curiosity and Exploration Inventory" [5] – a ten item Likert-scale inventory in which respondents self report their seeking of new knowledge or experiences, and their response to uncertainty and unpredictability.

Grit: "Grit" as a psychological construct is defined as perseverance and passion for long-term goals [6] and can be divided into two aspects:

1. *Consistency of interests* over time, and
2. *Perseverance of effort* over time.

We used their 12-item "Grit scale" [6] and expressed the results as a single, averaged score between 1 and 5.

Creativity: The "circles and squares" variant of the Torrance Test of Creative Thinking [7] was used to assess four domains of creative thinking in response to a stimulus:

1. *Fluency* refers to the number of ideas generated,
2. *Flexibility* the number of categorically different ideas,
3. *Originality* the rarity of the response relative to average, and
4. *Elaboration* the amount of detail in a response.

Students were given a sheet of paper with 42 identical circles in a 6×7 matrix. They were instructed "Use these circles as a basis for drawing. Draw for 3 minutes." Figural tests of creativity have been found to have good reliability and validity [8]. To score the responses, all the assessments were combined - those taken at the beginning and end of the course and from both sections of the course (with and without academic advising). We ranked the responses according to *originality* relative to the entire group, and divided them into five groups with equal numbers of responses, forcing us to use the entire 1-5 scale. The responses were subsequently rank-ordered for *elaboration*. This process ensured that we assigned scores relative to the two groups as a whole. In contrast, *fluency* and *flexibility* were simple counts and therefore not relative.

Engineering design self-efficacy: We previously measured *engineering self-concept* (self-association with engineering) as a psychological construct, and found that it did not change over the course of a single semester, and possibly not over the course of an entire career [9]. Thus, we instead measured self-efficacy – self-perceived ability or willingness to engage in engineering) using the 36-item "Engineering design self-efficacy instrument" [10] – that is, whether students feel:

1. *Able*, and
2. *Motivated* to engage in engineering design tasks, whether they feel they will be
3. *Successful* in doing so, and how
4. *Apprehensive* they would be in performing such tasks.

We made two mathematically linear changes to the scoring of this instrument: the Likert scale was reduced to 3 selections (low-medium-high) rather than 10 and we used summed rather than averaged scores.

Creative design: The final product of the design-build experience was scored on Nilsson's Taxonomy of Creative Design [11]. This taxonomy classifies a work as being:

1. *Imitation* – the replication of previous work,
2. *Variation* – modification of previous work in a way that retains the essential form of the original,
3. *Combination* – when two or more works are combined in a way that changes the essential form of both,
4. *Transformation* – reimagines a work such that the essential form is new, and
5. *Original creation* – has no discernable qualities of pre-existing works.

We scored each of the final builds with the numerical values shown above (1-5).

Delivery of the assessments: The instruments for curiosity, grit, and self-efficacy were delivered online, whereas the instrument for creativity was delivered on paper – the process knowledge instrument to enforce the time requirements, and the curiosity instrument both to enforce time requirements and because paper is a more amenable medium for drawing than is the typical computer. Scoring of creative design was performed *post hoc* by consensus of the instructor and the teaching assistants.

Analysis: Multiple-choice scores were tallied using Matlab. All the data were analyzed in SPSS.

Results

Student demographics: The advising section of the course enrolled 33 students, while the non-advising (control) section enrolled 42. The students were divided into 6 and 7 teams, respectively, based on their interest in particular project concepts. In total, there were 43 men and 32 women, proportionately divided between the sections.

Change over the first semester: We aggregated data from the two sections of the course to determine whether there was a significant change in psychometrics over the course of the

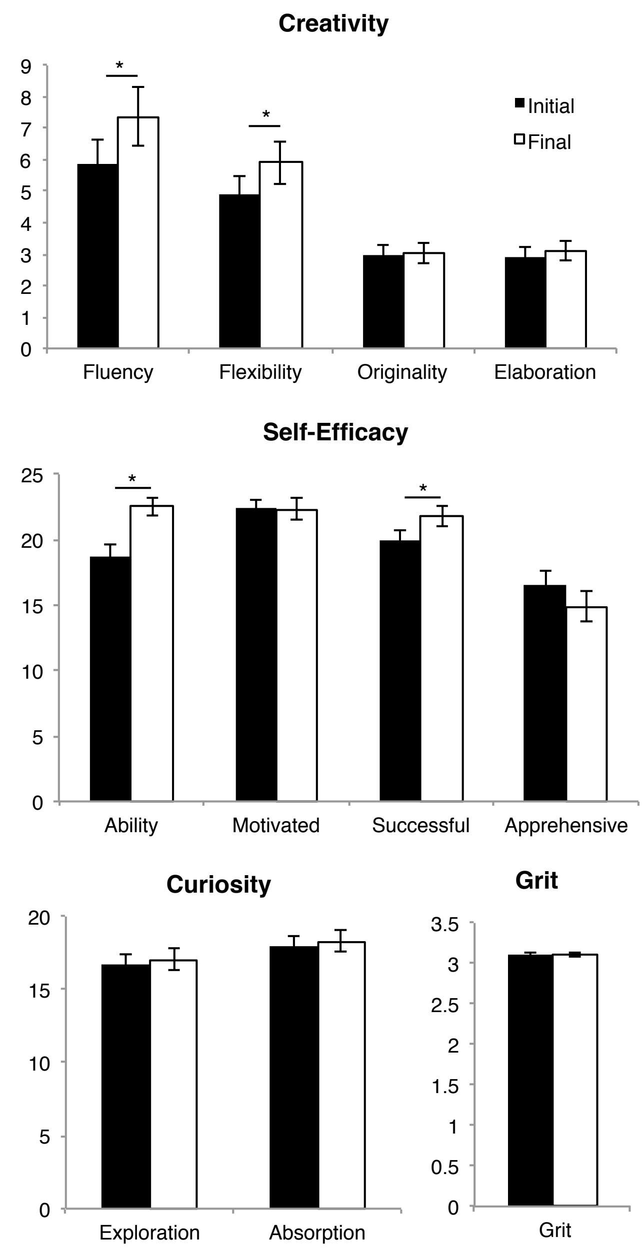

Figure 1: A comparison of scores for the four psychometric measures at the beginning (black) and end of the semester (white) independent of class section. *p<0.05 initial vs. final. The error bars show the 95% confidence intervals.

semester, presumably due in part to the hands-on design/build experience. Beginning and end of semester scores were compared using a paired t-test and are shown in Figure 1.

Indeed there were some changes over the course of the semester. We found positive trends in the *fluency* (number of ideas) and *flexibility* (categorically different ideas) aspects of *creativity* over the course of the semester ($p = 0.003$ and 0.003, respectively). These 25% and 21% improvements, respectively, are substantial for this particular metric. The originality and elaboration aspects of curiosity were unchanged.

We also found significant improvements in two of the four measures of *self-efficacy*. Students became more confident of their *ability* to engage in engineering design ($p < 0.001$) with a very large effect size of 1.2 (Table 1). They also grew more confident that they would be *successful* ($p < 0.001$), and less *apprehensive* about the process ($p = 0.12$). Interestingly students' degrees of *motivation* to engage in engineering design were unchanged, perhaps because they enter college already motivated toward these sorts of activities; indeed, the raw motivation score was exceptionally high in pre-testing (87% relative to the maximum score).

In contrast, we found only modest changes over the semester in *curiosity*, and no change at all in *grit*. Thus while curiosity and grit appear by this measure to be immutable, aspects of creativity and self-efficacy significantly improved over the course of the semester.

Differences between sections:

In order to reveal any pre-existing differences between the sections, we compared their initial assessment scores using an independent t-test. The sections differed in only two respects, both related to *curiosity*. The section with advising scored 12% higher than the control on *stretching* (p = 0.02) and 10% higher than the control on *embracing* (p = 0.02). Also, the advising section expressed a significantly higher sense of *self-efficacy* in how *successful* they would be in the design process (10%, p = 0.02, data not shown). These comparisons set a baseline for interpreting changes over the course of the semester. They also showed a need to control for initial psychometric scores in the analysis of variance for comparison of the final psychometric scores.

Thus, we performed an analysis of covariance for the final assessment scores, controlling for the initial assessment scores and again found only two areas of significant difference between the sections – in *creativity*, and in *self-efficacy*. These two areas of difference between the sections are the same as those that changed over the course of the semester (Figure 1).

Construct	Aspect	p	d
Creativity	Fluency	0.003	0.39
	Flexibility	0.003	0.36
	Originality	0.87	0.02
	Elaboration	0.20	0.15
Curiosity	Stretching	0.19	0.13
	Embracing	0.19	0.13
Self-efficacy	Ability	<0.001	1.19
	Motivated	0.93	0.01
	Successful	<0.001	0.58
	Apprehensive	0.12	0.38
Grit	Grit	0.13	0.00

Table 1: The significance and effect size (Cohen's d) of the improvement in psychometric aspects over the course of the semester, comparing the beginning to end of the course regardless of section. Significant differences between the sections are shaded in gray.

The control section performed better than the advising section of the course on two of the four aspects of *creativity* – *fluency* by 28% (p = 0.006), and *flexibility* by 24% (p = 0.04) – while the advising section did better than the control section on *originality* by 32% (p = 0.007). There was no difference between the sections in the *elaboration* aspect of *creativity* (p = 0.6). The effect sizes were moderate[12], ranging from 0.42-0.6 (Table 2).

The advising section also scored higher by 3% in the *successful* aspect of *engineering design self-efficacy* (p = 0.01), but the effect size was small (0.22). Thus improvements in engineering design self-efficacy over the course of the semester shown in figure 1 were probably the result of the design-build experience, which was common to both sections.

The overall gains in *creativity* and *self-efficacy* that we saw in the pooled data over the course of the semester (Figure 1) were primarily the result of significant gains by students in the control group. This becomes obvious when we graph the difference in scores as a measure of improvement – that is final minus initial-assessment values (Figure 2). In fact, the control section showed greater gains than the advising section in nearly all of the psychometric measures, disregarding statistical significance. There were trends toward the control group showing greater *creativity*, *self-efficacy* and less *apprehension* in design ability, greater *curiosity*, and more *grit*. These improvements in *curiosity* in the control section were positively correlated with higher course grade (p = 0.008).

Gender: We found no significant (p < 0.05) differences in any of the psychometric measures comparing men to women (data not shown).

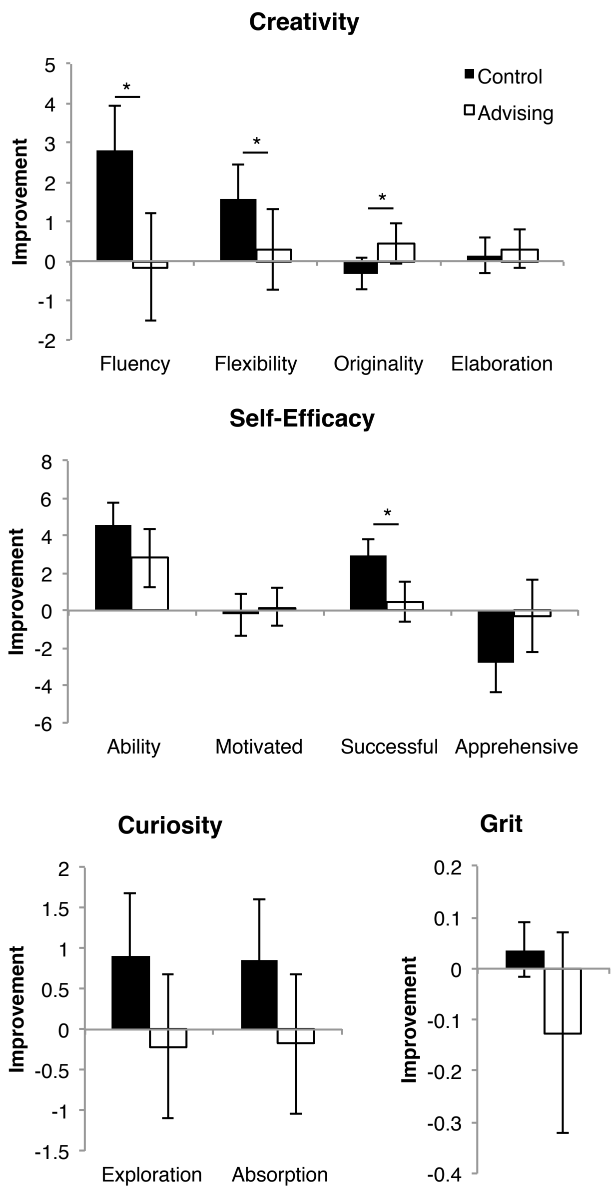

Figure 2: Improvement (final-initial difference scores) in psychometric measures by section. Positive scores indicate a semester-long improvement, while negative scores indicate a decline. The control section (black) outperformed the advising section in statistically significant meatrics. *p<0.05 controlling for pre-scores. Error bars show the 95% confidence intervals.

Project scores: There were no significant differences between the sections in the scores on their final prototypes, their final reports (invention disclosures), or their final presentations as measured by z-test (data not shown). The trend was toward the advising section outperforming the control section on these measures by a few percent. However, since students were scored as teams rather than as individuals on each of these, the number of independent samples was low.

There was, however, a trend toward differences in the creativity of the end-product. As measured on the taxonomy of creative design, the final works of the advising section were more creative than the control section by 17% (p=0.07).

End-of-course evaluations: The two sections of the course were unaware that they were in any way different from one another, yet the advising section ranked both the course itself (p = 0.12) and instructor (p = 0.07) more highly than did the control section in end of course evaluations. In an informal discussion with each section at the end of the course (after evaluations have been submitted), the students were informed of the difference (integrated advising versus team meetings). Not surprisingly, both sections felt that the advising section may have been at a relative disadvantage in class, but at a relative advantage "in life" (as one student put it). However, many students in the control section felt that weekly in-class team meetings were redundant (since they also meet outside of class) and therefore unnecessary.

At that same informal discussion, we collected students' perceived benefits of the intensive design-build environment. Both sections shared most views. When asked "what did you learn as a result of this process," students' replies included (student's wording):

- Fail early
- Embrace change
- Building something takes a very long time
- Embrace interdisciplinary projects and diversity on teams
- Knowledge of tool use
- The feasibility of making things
- The importance of teamwork
- Capitalize on the strengths of individual team members
- Don't expect things to work on the first time
- Brainstorming is important
- Get advice and feedback
- Test, test, test, all the time, every step of the way
- Document everything
- Second opinions are important. Get feedback from people outside your team

Each of these was a realization that we hoped the students would attain through the intensive design-build experience.

Discussion

Our data show that some psychological constructs with relevance to engineering education are mutable by first year experiences. These include *creativity* and *engineering design self-efficacy*, though this effect may also extend to *curiosity* and *grit*. This is an important finding, given the central role of *creativity* in the engineering design process. *Grit* too is vital, as it predicts educational attainment, grade point average, and academic retention[6]. While the entire psychometric space has yet to be explored in terms of its relevance to engineering education and engineering practice, the very nature of each of these constructs suggests their value.

Construct	Aspect	p	d
Creativity	Fluency	0.01	0.45
	Flexibility	0.04	0.42
	Originality	0.01	0.60
	Elaboration	0.60	0.10
Curiosity	Stretching	0.34	0.20
	Embracing	0.40	0.22
Self-efficacy	Ability	0.43	0.11
	Motivated	0.24	0.44
	Successful	0.01	0.22
	Apprehensive	0.29	0.07
Grit	Grit	0.09	0.32

Table 2: The significance and effect size (Cohen's d) of the improvement in psychometric aspects over the course of the semester, comparing the control to advising sections of the course. Significant differences between the sections are shaded in gray.

Surprisingly, greater improvements in virtually all our psychometric measures were seen in the control group, whose learning environment forced repetitive interactions among team members. In contrast, the psychometrics barely changed over the course of the semester for students in the advising section. This refutes our original hypothesis that a learning environment with additional emphasis on academic advising would bolster these traits.

Greater improvement of the control section over the advising section was perhaps due to inadvertent, repetitive brainstorming in the weekly team meetings. When visiting with the groups, we often emphasized the need to generate more ideas to solve specific as well as general aspects of their problem. This is essentially the Osborn-Parnes process, which relies on rounds of brainstorming to improve the creative process [13]. Torrance noted in a meta-analysis that the

Osborn-Parnes process may be one of the only effective ways of fostering *creativity* in children [3]. Studies have also suggested that the Osborn-Parnes process improves *self-efficacy* [14,15]. Thus this single pedagogical activity may explain both areas of significant difference that we observed.

Our data also agree well with earlier findings in 2nd grade children [16]. Those authors found that when comparing a learning environment with strong advisement to one that is more self-guided, achievement scores were higher in the self-guided group. Further, the higher achievement scores were correlated with higher *curiosity* scores [16]. In a related finding, curiosity has found to be closely correlated with intelligence[17]. Consistent with this, we found a significant correlation between changes in *curiosity* and course grades in our control group, which was low in advisement. Thus, *curiosity* is either covariate with grades in a low-advisement, more self-guided environment, or is a proximal determinant of grades in such an environment.

It is also worth noting that *curiosity* and *creativity* are positively correlated with one another ($p = 0.02$), but that they both show a weak negative correlation with *grit*. Others have noted a negative correlation between *creativity* and *grit* among professional scientists[18]. While persevering toward a goal may weaken exploration of alternatives, they also suggest that either these constructs or their associated measurement instruments are non-orthogonal.

There are alternative instruments for measuring most of the psychological constructs that we tested, including *creativity* ([19] among others), *grit* [20], and *curiosity* ([21,22] among others). The diversity of instruments suggests that the constructs themselves are weakly defined. Not only are psychological constructs, by their nature, open to debate as to their meaning, but also the factor analysis has been called into question that is often used to validate their measurement instruments [23].

Regardless, we feel that the time has come to bring these and other psychometric measures to the study of engineering pedagogy. A brief examination of syllabi, course descriptions, and pedagogical objectives shows that we often inadvertently also define psychological constructs and objectives. For example, the posted description for the introductory course herein described contains phrases including:

"the role of *creativity*"
"a *significant*, hands-on, case study project"
"*fun* and *challenging*"
"requiring a *balance*"
"*cultural*, *political* and other *considerations*"

Each of these has strong psychological components; after all, what is "fun?" At what level of difficulty does an individual find a task "challenging?" Some of these are reflected in aspects of the so-called "big five" personality traits – *Conscientiousness, Extraversion, Neuroticism, Agreeableness, and Openness to Experience*. Each is a well-validated psychometric construct, and some have been correlated to the success of student design teams [24]. Further, these traits tend to change rapidly in the college age group [25]. Instructor traits might be equally as important. For example, *grit* in a teacher is positively correlated with student achievement [26].

The students as a whole indicated they felt that the control (non-advising) section was at an advantage in the class; this is indeed supported by our data. However, there seems to be an intangible component that the advising section felt gave them an advantage in other respects. While it may be impossible to measure this advantage “in life” at the end of only one semester, it would be interesting to look over the course of these students’ college careers at the level of student engagement, interactions with professors, and other metrics that might have been affected by advising. These longer-term academic goals are of current and growing interest to colleges and universities[27]. While it is beyond the scope of this study, it could be beneficial to determine if integrated advising does in fact have some advantages, has any measurable effect on their success. If so, that would indicate that a small advising component to this type of class that emphasizes brainstorming and iteration in the design process would have added benefit.

There is certainly the sense that more has changed between the sections than we have measured here. These changes might be in purely psychological constructs, or they might be in affective development [28] (which is implicitly psychological), or in psychomotor development [29,30] (skill development). The former is rarely considered, much less measured, even though its counterpart in the cognitive domain [31] has been relied upon to the exclusion of the others for decades. With further development and refinement, psychometrics could become a valuable means for determining the broad-ranging benefits of educational interventions.

Finally, these data support the current educational trend toward self-guided learning environments. For example, *curiosity* fostered through “information gaps” is central to the practice of enquiry based learning[32]. However, rather than providing evidence of improved *academic* outcomes as a result of such environments, we suggest that there are additional and larger benefits in non-cognitive domains of learning. These, however, are but a single point on the spectrum of educational approaches. Traditional lecture-based environments, hybrid, and blended learning environments should also be compared in a pre-post fashion using psychometrics relevant to engineering practice.

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